

Measuring the baryon fraction in cluster of galaxies with Kinematic Sunyaev Zeldovich and a Standard Candle

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We propose a new method to use the Kinetic Sunyaev-Zeldovich for measuring the baryon fraction in cluster of galaxies. In this proposal we need a configuration that a supernova Type Ia resides in a brightest central galaxy of low redshift cluster of galaxy. We show that this supernova Type Ia can be used to measure the bulk velocity of a galaxy cluster in low redshifts where the main contribution to the standard candles distance modulus deviation from background prediction comes from peculiar velocity of the host. Then we argue that by the knowledge of the bulk flow of the galaxy cluster and the Cosmic microwave background photons temperature change due to kSZ, we can constrain the baryon fraction of galaxy cluster. The probability of this configuration for clusters in low redshift $z < 0.15$ is obtained. We estimate that in a conservative parameter estimation the large synoptic survey telescope can find ~ 30 galaxy clusters in low redshift with a bright central galaxy which host a type Ia Supernova. Finally, we show that the improving of the distance modulus measurement in future surveys is crucial to detect the baryon fraction of cluster with the proposed method.

I. INTRODUCTION

The baryon density of the Universe and its ratio with respect to the dark matter is fixed by Cosmic Microwave Background (CMB) radiation [1] and Big Bang Nucleosynthesis (BBN) [2] to a fraction of $f_b = \rho_b/\rho_m \simeq 0.16$. However this ratio is smaller by a factor of 2 or 3 in galaxies and cluster of galaxies. This is known as the missing baryon problem [3]. It is believed that the missing baryons are in intergalactic medium in diffuse warm-hot plasma which is hard to detect in X-ray or/and they are not in virialized gravitationally bound objects and resides in voids and filaments [4]. Also there is an idea that a considerable amount of missing baryon could be in cold transparent molecular clouds, which can be detected via optical scintillation method [5]. The search for the missing baryons is one of the ambitious quests of cosmology, which will shed light on the process of galaxy formation and evolution. One of the promising cosmological probes to address this problem is the study of the galaxy clusters as the largest gravitationally bound systems. It seems that the galaxy clusters less suffer from the missing baryon problem than the other structures, however they are very valuable structures in Universe to check the consistency of the universal baryon fraction [6]. We can learn about the physics of baryons in galaxy clusters by studying the interaction of the galaxy cluster with CMB photons. Although less than one percent of the CMB photons passed through the galaxy clusters but the physics of the interaction is known and under control. The inverse Compton scattering of CMB photons by hot intra-cluster gas of electrons change the intensity of the observed CMB. This effect is known as Sunyaev-Zeldovich (SZ) effect [7–9]. The bulk motion of the galaxy cluster also introduce a Doppler shift effect on the CMB photons known as kinetic Sunyaev Zeldovich (kSZ) effect [10]. The kSZ is a physical processes of electron-photon scattering which keeps the CMB spec-

trum almost unchanged, while the thermal Sunyaev-Zeldovich (tSZ) is a process that changes the CMB spectrum. We should note that for a typical cluster of galaxies the thermal velocities are higher than the bulk velocity and accordingly kSZ amplitude is an order of magnitude smaller than the tSZ. Thermal SZ is observed via CMB temperature [11, 12] and also from individual cluster studies [13, 14]. The kSZ is more challenging to be detected because of the smaller amplitude and also the fact that it does not change the spectrum of CMB. Despite to its observational challenges, kSZ is a very valuable quantity to be measured in clusters where it can be used to address some astrophysical questions like missing baryon problem [15, 16] and also some cosmological questions like the study of the growth of structures to constrain dark energy and modified gravity theories [17–21]. It is worth to mention that there is a frequency band in CMB observations $\nu \sim 218\text{GHz}$ where the tSZ change on the CMB is almost zero. The first detection of kSZ is reported by Hand et al. (2012) [22] used the correlation of the Atacama Cosmology Telescope (ACT) data [23] with the pair-wise velocity of the Baryon Oscillation Spectroscopic Survey (BOSS) spectroscopic catalogue [24]. The kSZ signal is also detected in Planck and Sloan data [25], South Pole Telescope and Dark Energy Survey cross correlation as well [26].

In this work we propose a novel idea to measure the baryon fraction in cluster of galaxies by using the kSZ effect. The temperature change due to the kSZ is proportional to the baryon fraction and the bulk velocity. In the case if we can find out the bulk velocity of the galaxy cluster then we can pin down the baryon fraction more accurately by adding the CMB-kSZ information. The main idea of this work is centered on the bulk velocity measurement. The bulk velocity is usually measured by using the X-ray catalog of clusters as a complimentary probe to kSZ [27] or it is obtained via reconstructed matter density field [28]. In this direction we suggest to use standard candles such as Supernova (SNe) type Ia to measure the bulk velocity. Traditionally SNe Ia used as a probe of cosmic bulk flow [29]. In this work we assume that the SNe resides in the brightest central galaxy of a cluster,

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accordingly this can be used as a probe of bulk velocity of cluster. Finally adding up the two independent observations of kSZ and SNe Ia, one can use it as a probe of baryon fraction in cluster. We also discuss the observational prospects of this proposal and the probability that this configuration can be observed. The structure of this work is as follows: In Sec. (II) we discuss the theoretical framework of kSZ. In Sec. (III) we discuss the idea of measuring the peculiar velocity via SNe type Ia. In Sec. (IV) we discuss the observational prospects of the idea raised in this work and finally we conclude in Sec.(V).

II. KSZ AND THE BARYON FRACTION

The temperature change in the CMB due to Kinetic Sunyaev-Zeldovich (kSZ) is as below

$$\frac{\Delta T}{\bar{T}}|_{kSZ}(\hat{n}) = -\frac{\sigma_T}{c} \int \frac{d\chi}{1+z} e^{-\tau(\chi)} n_e(\chi \hat{n}, \chi) \vec{v}_e \cdot \hat{n}, \quad (1)$$

where \bar{T} is the mean CMB temperature, $\chi(z)$ is the comoving distance which is a function of redshift z , σ_T is Thomson scattering cross section, τ is the optical depth, n_e is the physical number density of free electrons, \vec{v}_e is the peculiar velocity of free electrons and \hat{n} is defined as the direction of the observation away from observer. Note that the optical depth is defined as $\tau = \int dl n_e \sigma_T$. (where l is the physical length of the ionized patch in the sky).

This signal is an order of magnitude lower than the tSZ and does not change the black body of CMB temperature. This signal is extracted from the cross correlation with the late time tracers of gravitational potential. In this framework the leading science is done by Atacama Cosmology Telescope (ACT), which detect the kSZ signal in correlation with the LSS by correlating the kSZ signal with reconstructed velocity field obtained for the galaxies from Baryon Acoustic Oscillation Sky Survey (BOSS)[16]. In a standard way of thinking about the kSZ effect, It seems that the signal on CMB plus our knowledge on properties of galaxy cluster can be used to obtain the peculiar velocity of the free electrons. Now let us look to this problem in another point of view, if we can find the peculiar velocity of the galaxy cluster from an independent way, then we can use the kSZ signal to extract the information about the baryon fraction in a cluster of galaxies. One way to reconstruct the peculiar velocity is by the linear perturbation theory, the semi-local density contrast can be used as a probe of peculiar velocity by using the Euler equation [30]. The other method is to use the standard candles like SNe type Ia to extract the information. We will discuss this method extensively in Sec.(III).

In what follows we reexpress the kSZ signal in terms of two contributions: a) The Physics of baryons, b) The physics of peculiar velocity. With this point of view we write the physical number of electrons n_e as

$$n_e \simeq \Delta \bar{n}_e, \quad (2)$$

where \bar{n}_e is the cosmic background number density of electrons and Δ is the electron density contrast which is in order of $\simeq 200$ for a virialized cluster. The background number density of electrons can be expressed in terms of cosmological parameters as

$$\bar{n}_e = \Upsilon \frac{\rho_g(z)}{\mu_e m_p}, \quad (3)$$

where ρ_g is the mean gas density in redshift z , m_p is the proton mass and μ_e is the effective number of electrons per nucleon. Accordingly $\mu_e m_p$ is the mean mass per electron. Υ is the ionization fraction which depends on the temperature of the cluster and it is defined as $\Upsilon = [1 - Y_p(1 - N_{He}/4)]/(1 - Y_p/2)$, where Y_p is the primordial abundance of Helium and N_{He} is the number of ionized electrons corresponding to Helium atoms. Now we can relate the gas density to the baryon fraction of universe and matter density of universe as below

$$\rho_g = \frac{3H_0^2}{8\pi G} f_g f_b \Omega_m (1+z)^3, \quad (4)$$

where f_g is the gas fraction of baryons in a cluster and f_b is our crucial parameter of the study, known as baryon fraction parameter. Ω_m is the matter density parameter and H_0 is the Hubble parameter both defined in present time. Now by assuming that the evolution of all above parameters inside a cluster is negligible and position independent, the kSZ effect will become

$$\frac{\Delta T}{\bar{T}}|_{kSZ}^i \simeq -\sigma_T \ell^i e^{-\tau} (\Delta \bar{n}_e) \times \vec{\beta}^i \cdot \hat{n}, \quad (5)$$

where ℓ^i is the size of the cluster numbered i . The superscript i indicate the cluster's id. and $\vec{\beta} \equiv \vec{v}/c$. Now by using Eq.(3) and Eq.(4), it is straightforward to show that the signal can be written as

$$\frac{\Delta T}{\bar{T}}|_{kSZ}^i = -[C_i f_b \exp(-C_i f_b)] \times (\vec{\beta}^i \cdot \hat{n}), \quad (6)$$

where C_i is a specific parameter for each cluster, which depends on the mean redshift, the physics of intra-cluster medium and the line of sight length of the cluster as

$$C_i(z_i) = \frac{3H_0^2}{8\pi G} \frac{\sigma_T}{\mu_e m_p} (\Delta f_g \Upsilon \ell^i) \Omega_m (1+z_i)^3. \quad (7)$$

Now C_i can be written in the terms of cluster's gas fraction, ionization factor and line of sight length

$$C_i(z_i) \simeq 4 \times 10^{-3} \times \Omega_m h^2 (1+z_i)^3 f_g \Upsilon \frac{\ell^i}{Mpc}. \quad (8)$$

Finally, we can define a parameter $x = -C_i f_b$ for each cluster, which encapsulates in it the physics of baryonic matter and it is related to kSZ temperature change and the bulk flow of the cluster as below

$$x \simeq \left(\frac{\Delta T}{\bar{T}}|_{kSZ}^i \right) / (\vec{\beta}^i \cdot \hat{n}), \quad (9)$$

where the approximation works for $\Omega_m = 0.3$, $h = 0.7$, $\ell^i \simeq 1 Mpc$, $\Upsilon \simeq 1$, $f_g \leq 1$ and $f_b \leq 0.16$. This means that by knowing the temperature change of the CMB due to the kSZ effect and the peculiar velocity measurement by an independent method we can constrain the physics of free electrons and baryon fraction in a cluster. In the next section we will discuss that, how SNe type Ia will be a great candidate in order to calculate the bulk flow parameter.

III. STANDARD CANDLES AS A PROBE OF PECULIAR VELOCITY

In this section we will discuss how standard candles can be used to determine the peculiar velocity of the structures. The idea is straightforward, the standard candles are used to establish a luminosity distance-redshift relation for a given background cosmology model. However the deviation from the homogenous background will change this relation. One of the important modifications is due to the peculiar velocity of the host galaxy of a SNe, which affects both the luminosity and redshift of the standard candle. Accordingly, we can use the deviation of the luminosity distance of the SNe Ia as a probe of peculiar velocity.

For this task, we assume that we are living in a perturbed FRW universe with a Newtonian comoving gauge chosen metric

$$ds^2 = a^2(\eta) \left[-(1 + 2\Psi(x, t))d\eta^2 + (1 - 2\Psi(x, t))\delta_{ij}dx^i dx^j \right], \quad (10)$$

where η is the conformal time and Ψ is the scalar metric perturbation. We assume that the General Relativity (GR) is the correct classical theory of gravity and the universe is filled with components that have no anisotropic pressure. In this perturbed universe, the luminosity distance of a SNe Ia is corrected by the change in the space-time component of the light propagation induced by amount of the matter in line of sight (Sachs Wolf effect and gravitational lensing). The luminosity distance is also corrected due to the peculiar velocity of the source and observer. This is formulated in an equation for luminosity change [31–33]

$$d_L(z_s, \hat{n}) = (1 + z_s)\chi(z_s) [1 - \kappa_v - \kappa_g - \kappa_{SW} - \kappa_{ISW}], \quad (11)$$

where $d_L(z_s, \hat{n})$ is the luminosity distance of a supernova in observed redshift of z_s and direction \hat{n} (Note that \hat{n} is unit vector in the direction of observer toward source). $\chi(z_s)$ is the comoving distance in FRW universe in the observed redshift. The parameter κ_v is the correction due to peculiar velocity of source. The κ_g , κ_{SW} and κ_{ISW} are the lensing convergence, Sachs-Wolf and Integrated Sachs-Wolf correction terms. (This terms are defined and studied extensively in [32]). In the redshift range of $z < 0.15$ the most contribution to the luminosity distance change comes from the peculiar velocity [34]

$$d_L(z_s, \hat{n}) \simeq \bar{d}_L(z_s)[1 - \kappa_v], \quad (12)$$

where $\bar{d}_L(z_s)$ is the background luminosity distance and κ_v is luminosity correction due to peculiar velocity [31] defined as

$$\kappa_v = - \left(1 - \frac{1 + z_s}{\chi(z_s)c^{-1}H(z_s)} \right) (\vec{\beta}_s \cdot \hat{n}), \quad (13)$$

where H is the Hubble parameter and $\vec{\beta}_s = \vec{v}_p/c$ where (v_p is the peculiar velocity). In low and intermediate redshifts ($z < 1.4$), the term in parentheses is negative, accordingly the objects moving toward us ($\vec{\beta}_s \cdot \hat{n} < 0$) introduce a $\kappa_v < 0$ where if we replace this in Eq.(12) we will get a dimmer SNe. In the other hand when the host of a standard candle is moving away from us ($\vec{\beta}_s \cdot \hat{n} > 0$), that introduces a $\kappa_v > 0$ and accordingly the source become brighter. These chain of conclusions are changed in higher redshifts.

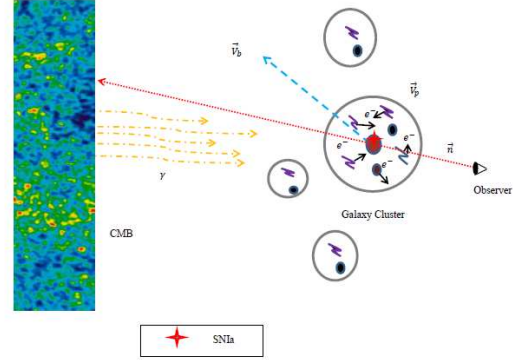


FIG. 1: A schematic configuration of a galaxy cluster is plotted which has a kSZ effect and its central bright galaxy, hosts a supernova type Ia. The dotted red arrow indicate the line of sight direction and the blue dashed arrow is the direction of the bulk flow. The solid black arrows shows the peculiar velocities of cluster members. Orange dashed dotted arrows shows the CMB photons which will interact with ionized plasma of galaxy cluster and the red star represent a SNIa.

The main idea of this work is that we can use SNe for finding the peculiar velocity (bulk flow) of the galaxy cluster. Before proceed further, we should numerate the velocity contributions to our specific case of study. The velocities which can be assigned to a SNIa explosion are:

a) The peculiar velocity introduced from the progenitor of the SNIa, b) The peculiar velocity of the host galaxy due to the gravitational potential of the cluster and c) The peculiar velocity due to the bulk flow of the galaxy cluster. In this work we are merely interested in bulk flow, accordingly in order to extract this term, which is the source of the kSZ effect, we assume, that the host galaxy of the supernova is the one which is located in the center of galaxy cluster (known as bright central galaxy (BCG)). The central galaxy assumption is needed, as we want to assign the bulk velocity of the galaxy cluster to peculiar velocity of the BCG. This means that bulk velocity of cluster, which is represented by free electron velocity

is the dominant term in host galaxy's peculiar velocity calculations. This fact comes from the idea that the central bright galaxies reside in the minimum of the potential well of cluster and the peculiar velocity with respect to the center of the mass of a cluster is smaller than the total bulk motion of the whole system. We assert that main contribution to the luminosity change of a SN in BCG is due to the peculiar velocity of the bulk motion of the cluster. This configuration is schematically shown in Fig.(1). However we should keep in mind that the effect of SNe Ia's progenitor's velocity *may* have a very significant velocity offset with respect to the peculiar velocity of the BCG host galaxy. This offset is included as a source of noise in our estimation. Keeping this in mind we proceed by assigning the velocity corrections of luminosity distance to the bulk flow. This can be done by the idea that the progenitor velocity introduce a gaussian error to the velocity estimation with the mean and a variance related to the dynamical mass of BCG. The mean and variance can be calculated by setting the velocity of the center of mass of a SNIa progenitor equal to the dispersion velocity inside a typical BCG using the fundamental plane relation of elliptical galaxies [35, 36], for a specific example, we express the dispersion velocity in terms of metric magnitude [37] as $\log_{10}(\sigma_{pro}/300\text{km s}^{-1}) = -(0.275 \pm 0.023)(M_m/2.5) - 2.55 \pm 0.21$ where M_m is the metric magnitude. In this work we set the mean velocity to $\sigma_{pro} \sim 300\text{km/s}$ with 10% variance. Now by using Eq.(13), we can find the line of sight normalized velocity as

$$(\vec{\beta}_s \cdot \hat{n}) = (1 - 10^{\Delta\mu/5})/\tilde{\kappa}_v, \quad (14)$$

where $\Delta\mu$ is the difference of the observed distance modulus and the one predicted from background cosmology of ΛCDM in the specific redshift of z_s . The parameter $\tilde{\kappa}_v = (1 + z_s)cH_0^{-1}/\chi(z_s)E(z_s) - 1$ is a unique term which is independent of the local physics, instead it depends on the background cosmological parameters and the redshift of the supernova. Note that $E(z_s)$ is the normalized Hubble parameter to its present value. Now by using Eq.(14) we can calculate the line of sight velocity of a SN, then we can assign this to the bulk velocity of the galaxy cluster which is the host of the SN $\vec{\beta}_s \cdot \hat{n} \equiv (\vec{\beta}^i \cdot \hat{n})$ where superscript i represent the host of a SN. Now by this identification we can use Eq.(9) to extract the baryon fraction. This can be done because the RHS of this equation is fixed by two independent observation. As mentioned in introduction the peculiar velocity measurement can be done in different methods like velocity reconstruction with a galaxy field[38] and can be cross-checked with the method presented here. In the next section we will discuss the observational prospects of finding the missing baryons by the method described in this work.

IV. OBSERVATIONAL PROSPECTS

In this section, we will discuss the observational prospects of the idea proposed in previous sections. In the first subsection, we use the data sample of Union 2.1 in order to represent

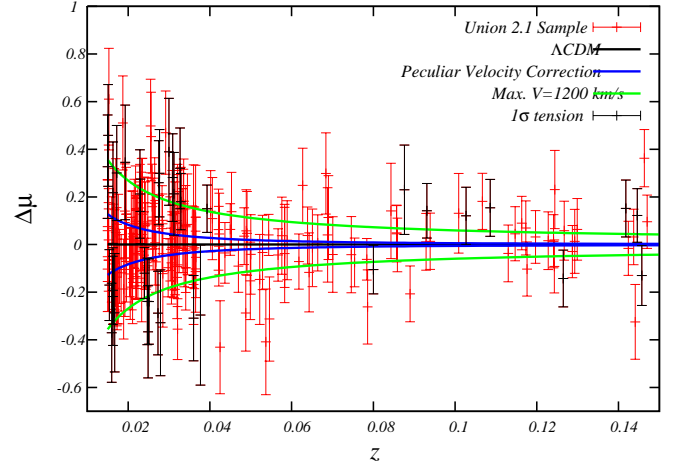


FIG. 2: The $\Delta\mu$ versus redshift is plotted for Union 2.1 sample of SNe Ia in redshift range of (0.015, 0.150) with 1σ error bar. The red data points shows the SNe that are consistent with background ΛCDM prediction (or far off from peculiar velocity correction (see the text)). The black points are in 1σ tension with background prediction. Low amplitude blue curves are obtained from linear theory and the high amplitude green curves are set by assuming a maximum velocity of 1200km/s for a typical cluster.

the logical path of extracting the bulk flow of the clusters from the data with assuming that each SNIa reside in a BCG. In the second subsection we discuss the error estimation for realistic and optimistic case for finding the baryon fraction and finally in the third subsection we present an estimate for the number of events that we anticipate in future surveys which are suitable for our case of study.

A. Union 2.1 SNe Ia data sample as preliminary example

In this direction first we assume that all the SNe data from the known catalog are a potentially plausible candidates for our proposal. It means that we assume that they are hosted by a central galaxy of the cluster. This is just an assumption to show the procedure that how we can extract the information about baryons in a cluster. Accordingly, we use the Union 2.1 SNe sample [39] to show the procedure. First of all we extract the peculiar velocity with the method describe in Sec.(III) by assuming that the standard ΛCDM model with best parameters fixed by supernova data [1] describe the cosmological flat background ($\Omega_m = 0.297$, $h = 0.704$). We obtain the difference of distance modulus $\Delta\mu = \mu_{obs} - \bar{\mu}$ versus redshift for the sample of SNe. Note that $\bar{\mu}$ is the distance modulus from the known background cosmology.

In Fig.(2), we plot $\Delta\mu$ versus redshift for SN Ia in redshift range of (0.015, 0.150). As it mentioned, in this redshift range the peculiar velocity correction is the dominant effect in the luminosity change of the SNe Ia [32, 34], where we neglect the contribution of weak lensing convergence and the Sachs-Wolfe effect. In Fig.(2) the red data points shows the SNe

data that are consistent with background Λ CDM predictions. The blue low amplitude solid curves represent the amount of correction that we expect from the peculiar velocity in linear regime. The linear regime velocity can be obtained via linear matter spectrum $P(k)$ as:

$$\langle v_p^2 \rangle(z) = \frac{H_0^2 f^2}{2\pi^2} \int P(k) W^2(kR(z)) dk, \quad (15)$$

where $\langle v_p^2 \rangle(z)$ is the average linear velocity in window function with a comoving radius R . The parameter f is the growth rate which for standard Λ CDM is equal to $f \simeq [(\Omega_m(1+z)^3)/E(z)]^{0.55}$ (Note that $E(z)$ is the normalized Hubble parameter to its present value). The blue curves shows the prediction of standard model in perturbation level. The solid high amplitude green lines are obtained by assuming a maximum line of sight velocity of 1200 km/s . The black points with their 1σ error-bars indicate that the chosen SNe Ia have a tension with background prediction as $\Delta\mu$ is not zero. However they are consistent by linear perturbation prediction or with a maximum velocity of 1200 km/s for a typical cluster. Accordingly we neglect the SNe that are out of the region of green curves with considering their error-bars (This set of SNe are also plotted in red points). The tension with the background can be interpreted as the effect of the first order correction to the distance modulus due the fact that cosmological model deviates from homogenous-isotropic background. Accordingly the black data points of SNe, potentially, can be interesting candidates in order to use them to extract the line of sight velocity of their host galaxies. In this procedure we fix the background parameters by merely using the SNe Ia data, however we can fix the background cosmology by complimentary observations such as CMB temperature anisotropy power spectrum. It is worth to mention that 58 SNe Ia data pass the mentioned criteria. In the next step, we assign the deviation of the distance modulus change to the peculiar velocity of the host galaxies. Reasonably, the next step is to find the line of sight (v_{los}) velocity of each SNe.

In Fig.(3), we use Eq.(14) to extract the line of sight velocity. Accordingly, we plot the v_{los} of those SNe that are in 1σ tension with background cosmological model versus redshift and are in the range of reasonable velocities. The error bars are obtained from the propagation of the error in distance modulus and also an error is added due to the velocity of SNe progenitors. For this task we use a Monte-Carlo method to add a Gaussian error with a mean of $\sigma_{pro} \sim 300 \text{ km/s}$ and a 10% variance. The very interesting point to indicate here is that the SNe that seems brighter ($\Delta\mu < 0$) moves away from us $\vec{\beta} \cdot \hat{n} > 0$. This observation is consistent to the argument we made before for peculiar velocity effect in low redshifts. In Fig.(3), we also obtained the peculiar velocity with an optimistic resolution. The blue small error-bar data come from the assumption that the *relative* error-bars of distance modulus in the optimistic case become half the realistic relative error that we have from the Union sample $\sigma_{sn(opt)} = 0.5\sigma_{sn(r)}$. This plots shows that how the accuracy in SNIa luminosity distance measurement are important in this study.

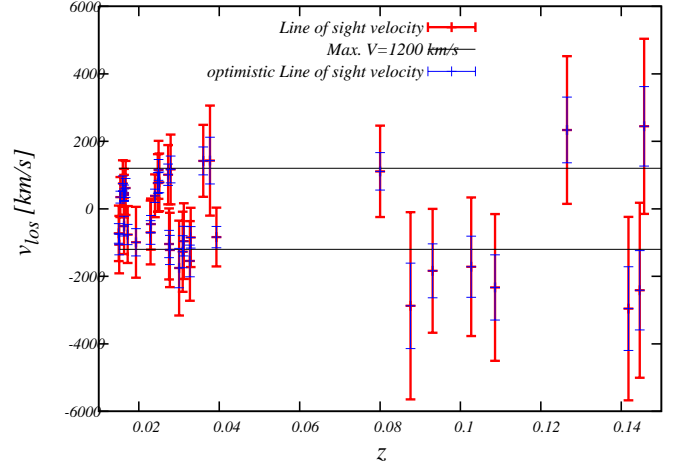


FIG. 3: The line of sight velocity of SNe is obtained from Eq.(14) is plotted versus redshift for the SNe of the Union sample which are in 1σ tension with the prediction of background cosmology. The horizontal solid black lines shows the typical maximum velocity of galaxy clusters $v_p \simeq \pm 1200 \text{ km/s}$. This plot is obtained for realistic and optimistic errors on SNe luminosity distance measurement. The uncertainty due to the progenitors are the same in considered cases.

In order to find out about the baryon fraction, now by knowing the kSZ temperature change for each galaxy cluster, we can find the baryon fraction keeping in mind that each SNIa galaxy host is the bright central galaxy of cluster under investigation. Then with this assumption we can find the baryon fraction with the relation below:

$$f_b^i \simeq \left[\left(\frac{\Delta T}{T} \right)_{kSZ}^i / \left(10^{\Delta\mu/5} - 1 \right) \right] \frac{\tilde{\kappa}_v}{C^i}, \quad (16)$$

where C^i obtained from Eq.(8) and $\tilde{\kappa}_v$ depends on the background cosmology. We should note that Eq.(16) is the key equation of our proposal. The baryon fraction of cluster can be obtained by its kSZ temperature change signal and the luminosity change of a SNe which is hosted by the central galaxy of cluster. In the next subsection we discuss the error propagation due to other components of Eq. (16), which will introduce the uncertainty in baryon fraction calculation.

B. The error estimation

In this section we show a forecast simple error calculation, in order to discuss the different error propagations in baryon fraction calculation. This can be used to show the usefulness of the method and its capacity for future experiments. For simplicity we assume that the background cosmological model is fixed via other observations such as CMB and the errors on density parameters and Hubble constant is much more smaller than the uncertainties in the physics of the cluster, supernova observations and kSZ signal extraction. This means that the uncertainty in baryon fraction calculation can be writ-

ten as

$$\sigma_{f_b}^2 = \left(\frac{\partial f_b}{\partial (\Delta T/T|_{kSZ})} \right)^2 \sigma_{kSZ}^2 + \left(\frac{\partial f_b}{\partial \Delta \mu} \right)^2 \sigma_{sn}^2 + \left(\frac{\partial f_b}{\partial C_i} \right)^2 \sigma_c^2, \quad (17)$$

where σ_{kSZ} is the error in kSZ signal from CMB analysis σ_{sn} is due to SNe Ia uncertainties due to intrinsic magnification errors and due to peculiar velocity of the SNe Ia progenitors and σ_c is related to the physics of the clusters. We also assume that errors from different contributions are uncorrelated and Gaussian distributed, which is almost a reasonable assumption. For kSZ the main problem is that the spectrum has almost a flat power in frequency range, that is why the primordial CMB anisotropies themselves are the most important source of contamination. Accordingly most of kSZ extraction methods try to separate the cluster signal of kSZ and primordial anisotropies. Regarding the angular resolution the galaxy cluster is of the order a few arc-minutes which is related to the angular moment of $\ell \sim 3000$. This is a good news since the primordial CMB anisotropies are damped for large moments. Accordingly a proper filter can separate the two signals. In a realistic error estimation, we set the relative uncertainty as $\sigma_{kSZ}/(\Delta T/T|_{kSZ}) \simeq 10\%$ [23] and for futuristic (e.g. CMB stage IV experiments) one we set $\tilde{\sigma}_{kSZ(opt)} \simeq 0.5\tilde{\sigma}_{kSZ(r)}$ [44] (Note that tilde is an indication of relative errors and subscripts "r" and "opt" are for realistic and optimistic cases respectively).

In the case of SNIa magnitude error, we have two contributions: one is from the intrinsic error in SNIa magnification and the other is from the progenitor of SNIa accordingly the relative uncertainty of SNIa become $\sigma_{sn}/\Delta \mu = [(\sigma_{sn(i)}/\Delta \mu)^2 + (\sigma_{sn(p)}/\Delta \mu)^2]^{1/2}$. For the realistic case the intrinsic relative error is obtained by setting an accuracy of one tenth of magnitude and for futuristic experiment like LSST we set the relative intrinsic error to $\tilde{\sigma}_{sn(opt)} = 0.5\tilde{\sigma}_{sn(r)}$. For both cases the progenitor relative error keep fixed. As the uncertainty in the SNe Ia has the main contribution to the baryon fraction, we present our forecast with $\tilde{\sigma}_{sn(opt)} = 0.1\tilde{\sigma}_{sn(r)}$ as well. Finally we come up with the relative error due to the physics of galaxy cluster, where the main contribution is raised from the size of the galaxy and the gas fraction of the cluster. The relative uncertainty is set $\tilde{\sigma}_c \simeq 10\%$.

In Fig. (4), we plot the Fisher forecast for each of the SNe Ia which are chosen as a promising candidates for our configuration. We set the fiducial parameter $f_b = 0.16$ and plot the 1σ prediction of our method for realistic and optimistic cases. In the optimistic case we consider two categories of $\tilde{\sigma}_{sn(opt)} = 0.5\tilde{\sigma}_{sn(r)}$ red points with the corresponding error bars and $\tilde{\sigma}_{sn(opt)} = 0.1\tilde{\sigma}_{sn(r)}$ blue points. In Fig.(5) we plot the one-dimensional confidence level for finding the fiducial baryon fraction with three cases of realistic errors and two optimistic cases.

In the next subsection we will discuss a very important issue of the probability of the detection of the configuration (SNe Ia in a BCG) which we proposed in this work.

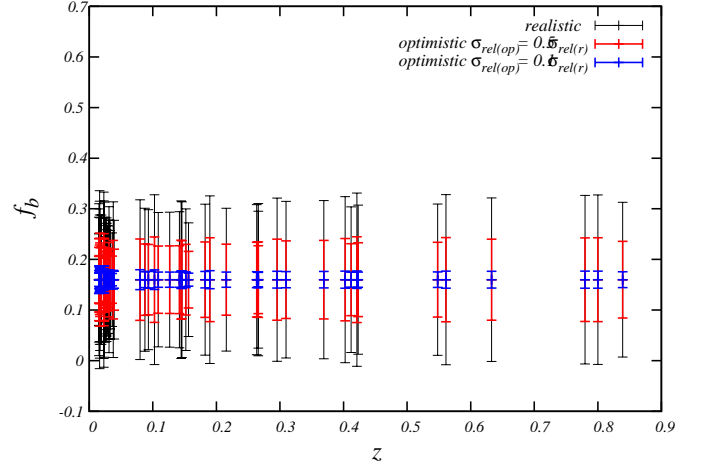


FIG. 4: The fiducial parameter of baryon fraction for SNe Ia that meet the criteria of peculiar velocity measurement with 1σ confidence level for realistic and two optimistic cases with $\tilde{\sigma}_{sn(opt)} = 0.5\tilde{\sigma}_{sn(r)}$ (red line) and $\tilde{\sigma}_{sn(opt)} = 0.1\tilde{\sigma}_{sn(r)}$ (black line).

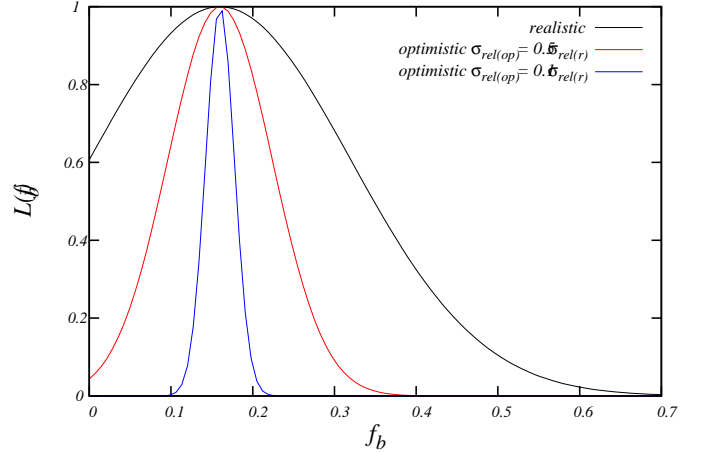


FIG. 5: The 68% constraints on fiducial parameter of baryon fraction due to realistic (current) errors on physics of cluster, kSZ and SNe Ia luminosity distance measurement and the optimistic errors $\tilde{\sigma}_{sn(opt)} = 0.5\tilde{\sigma}_{sn(r)}$ (red line) and $\tilde{\sigma}_{sn(opt)} = 0.1\tilde{\sigma}_{sn(r)}$ (black line).

C. The expected number of SNe Ia in BCG of galaxy cluster

In order to finalize our proposed observational method for baryon fraction, we should address the important question: "How many events of SNe Type Ia explosions are happened in the central galaxy of a cluster". We formulate this probability due to the simplified relation below where N_{obs}^{sn} is the number of observed brightest central galaxies with the desired condition of our proposal.

$$N_{obs}^{sn}(T_{obs}; s; bcg; \odot) = f_{sky} \times N_{bcg} \times P_{\odot} \times T_{obs}. \quad (18)$$

The $N_{obs}^{sn} = N_{obs}^{sn}(T_{obs}; s; bcg; \odot)$ is a function of the observation time T_{obs} and also it depends on the cosmological vol-

ume of the survey and the portion of the sky f_{sky} it spans. All of this information is encapsulated in symbolic parameter of s which stands for survey. It is obvious that the observed number of configuration depends on physics of BCG (indicated by "bcg") and the physics of SNIa (indicated by "o" in eq.(18)). The N_{bcg} is the number of central bright galaxies that resides in clusters which has a mass in the range of $M_l < M_{bcg} < M_u$, where M_l and M_u indicate lower and upper limit of a typical BCG which resides in the redshift range of z_i up to z_f . The parameter P_o is the probability that a SNIa occurred in a bright central galaxy of a cluster. The number of BCG in galaxy clusters in a cosmological volume, which is limited by the redshift range, that we are interested in is as below

$$N_{bcg}(M_l, M_u, z_i, z_f) = f_{bcg} \int_{M_l}^{M_u} dM \int_{z_i}^{z_f} dz \frac{dV}{dz} \frac{dn(M, z)}{dM}, \quad (19)$$

where we set $M_l = 10^{12.5} M_\odot$ and $M_u = 10^{13.0} M_\odot$ as the lower and upper limit of BCG, $z_i = 0.015$ and $z_f = 0.150$ is the lower and upper limit of the redshift survey that we are interested and f_{bcg} is the fraction of luminous massive galaxies that resides in the center of galaxy cluster. Due to the fact that bright central galaxies are assembled mainly by major mergers in galaxy formation and evolution process, there is an indication that the most massive galaxies must reside in galaxy clusters. We choose the very conservative estimate $f_{bcg} = 0.1$ for this study. In order to obtain the number density of cluster, we use the Press-Schechter approach to find dn/dM , specifically when we use the fitting function introduced in Jenkins et al [40]. Accordingly the number of BCG galaxies become $N_{bcg} \simeq f_{bcg} \times V_c \times 10^{-5}$, where V_c is the cosmological volume. Note that the effective volume is $V_c \approx 1 Gpc^3$ for a survey which is in search of galaxies in redshift span of $0.015 < z < 0.15$. Another important parameter is P_o to estimate is the rate of SN Ia in a galaxies with the given mass range. In Graur et al. [41], there is an extensive study on the rate of Type Ia supernova. Graur et al. used SNe samples to measure mass-normalized SNe rates as a function of stellar mass of the host galaxy and the star formation rate. By assuming the stellar mass of $10^{11.5} < M_* < 10^{12}$ (with the assumption of a mass to light ratio of ~ 10) and the star formation rate we will have the marginalized fitting function as $P_o \simeq 0.06 \times (M_*/10^{12} M_\odot)/year$. It is worth to mention that the SN rate is proportional to star formation rate and specific star formation rate, accordingly the rate of SN decrease with evolution of BC galaxies from active to passive ones. However in low redshift ($z < 0.15$), the specific star formation rate in BCGs is declining more slowly with time than for field or cluster galaxies, most likely due to the fuel from the cooling of inter-cluster medium [42]. With all this complicated physics which is governing the SNIa rate relation with the host galaxy, we set the conservative rate of $P_o \sim 0.01/year$.

A project like Large Synoptic Survey Telescope (LSST) which is designed to operate for 10 years starting from 2019 and will capable of spanning the 20,000 square degree of the sky (which means $f_{sky} \sim 0.5$) in 6 optical bandwidth with a

limited magnitude of to a total point-source depth of $r \sim 27.5$ [43], we can estimate the $N_{obs}^{sn} \sim 30$ with the conservative assumptions we made in this section. In another word in a very conservative point of view in LSST life time project we can estimate the baryon fraction of more than 30 clusters of galaxies.

V. CONCLUSION AND PROSPECTS

The distribution of the baryons in the Universe is one of the main questions in cosmology, the big bang nucleosynthesis and cosmic microwave background radiation independently fixes the baryon fraction. However the accessibility of baryons in late time is a challenging task and it seems that there is a missing baryon problem out there. The galaxy clusters as the main reservoir of baryonic matter are filled with ionized electrons, also nowadays there is an indications that the baryonic matter can be spread out in non virialized objects. One of the promising venues to address the distribution of baryons in the sky is the study of thermal and kinetic Sunyaev-Zeldovich effect which are used as a probe of ionized gas in clusters. In this work we propose a new idea/method to measure the baryon fraction using the kSZ effect and the SNe-Type Ia as the standard candle. For this method to work we assume that a SNIa explodes in a bright central galaxy of a cluster. This is essential in a sense that the peculiar velocity of a BCG in a cluster can be used as an almost fair representative of the cluster's bulk flow. The BCG resides in the depth of gravitational potential of cluster and its velocity with respect to the center of mass of the system is almost zero. However in this work we indicate that the main uncertainty comes from the velocity of the SNe Ia's progenitor. Accordingly we show that the SNe Ia in low redshift can be used to estimate the peculiar velocity of host galaxy. In the other hand The kSZ effects on CMB temperature change depends on the baryon fraction and the bulk velocity of galaxy cluster. We assert that the deviation of a standard candle distance modulus from background prediction of the Λ CDM can be related to the peculiar velocity of SNIa host galaxy in lower redshifts, keeping in mind that the host galaxy is chosen to be a BCG. We showed that by knowledge of the peculiar velocity and the temperature change of CMB we can constrain the baryon fraction. We investigate the Fisher forecast for the fiducial value of baryon fraction in the realistic (current) case and also in optimistic state. The analysis are discussed in the second subsection of Sec.(IV). In the observational prospect part, we also study the possibility of the observation of this effect. We estimate that in a future large scale survey, like LSST which spans half of the sky in ~ 10 years, we can observe at least ~ 30 SNe Ia which explodes in a BCG in a cluster of galaxy. It is worth to mention that in the case of more statistics in galaxy cluster we can average the peculiar velocity of each host galaxy of SNIa, the average of squared velocity will be a representative of the bulk flow and the dispersion of velocities represent the error bar on bulk velocity. The story of the galaxy clusters with a

BCG that host a SNIa can have another twist. In the case if we can pin down the properties of cluster like baryon fraction, the scale of a cluster and..., then we can find the expanding rate of the Universe via the proposal, that we made in this work encapsulated in $\tilde{\kappa}_v$ which is related to physics we investigate here as: $\tilde{\kappa}_v = C^i f_b^i [(\frac{\Delta T}{T})_{kSZ}^i / (10^{\Delta\mu/5} - 1)]^{-1}$. As a final remark we want to insist that incorporating the SNe Ia that occurred in galaxy cluster with the SZ effect can open up new horizons to study the physics of baryons and also can be used as a consistency check for our cosmological models.

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